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Impact of Alaskan Stream eddies on chlorophyll distribution in the central subarctic North Pacific*

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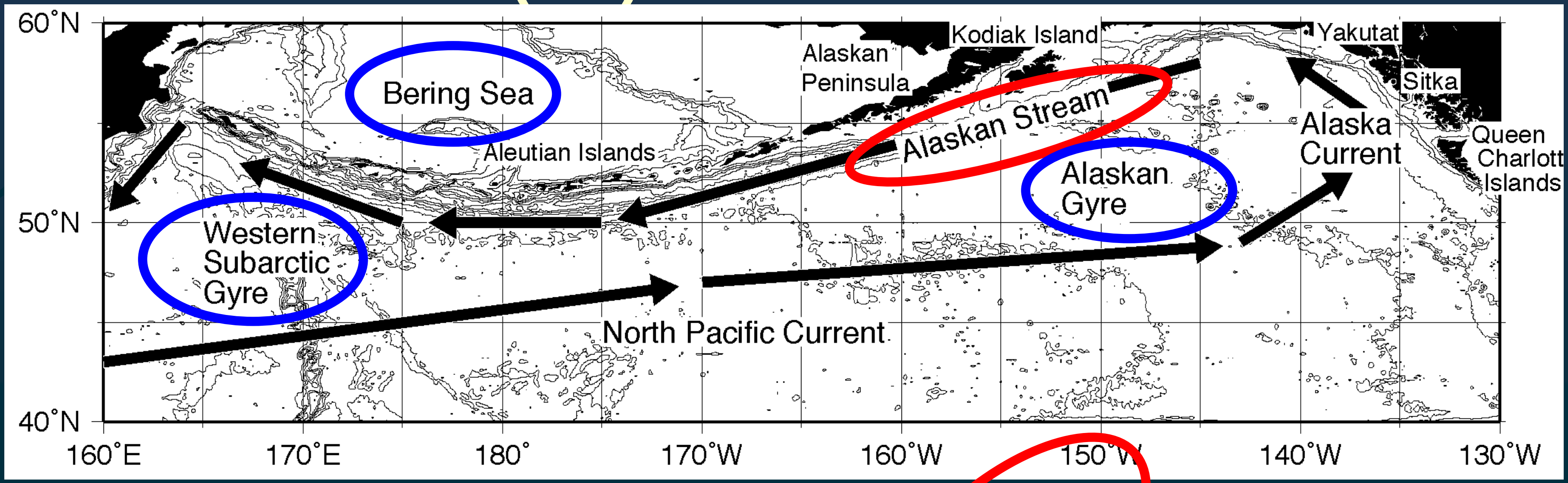
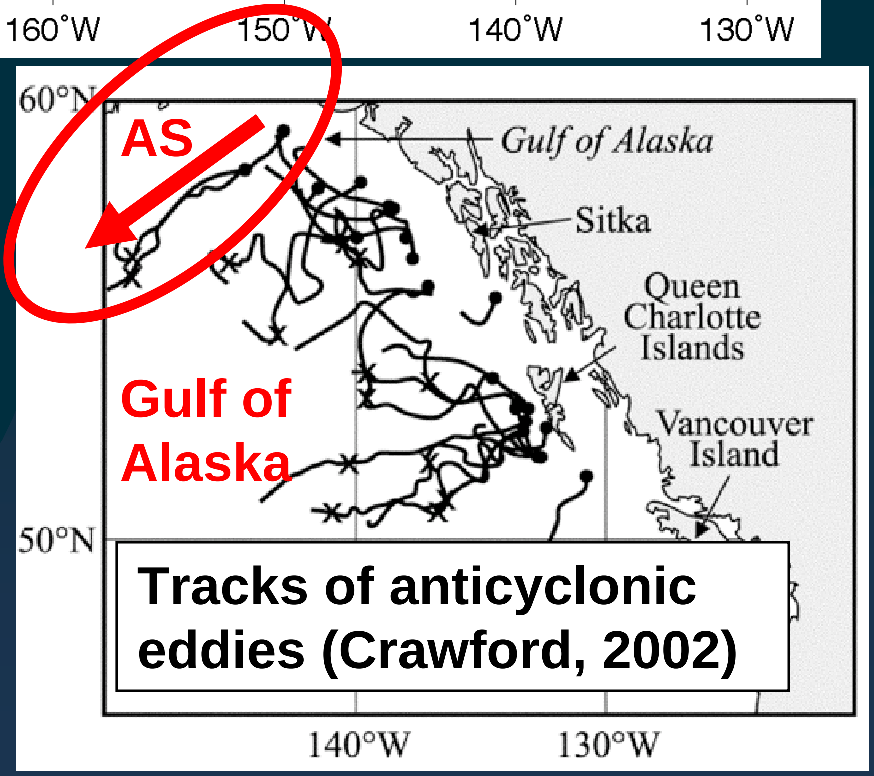
Alaskan Stream (AS)



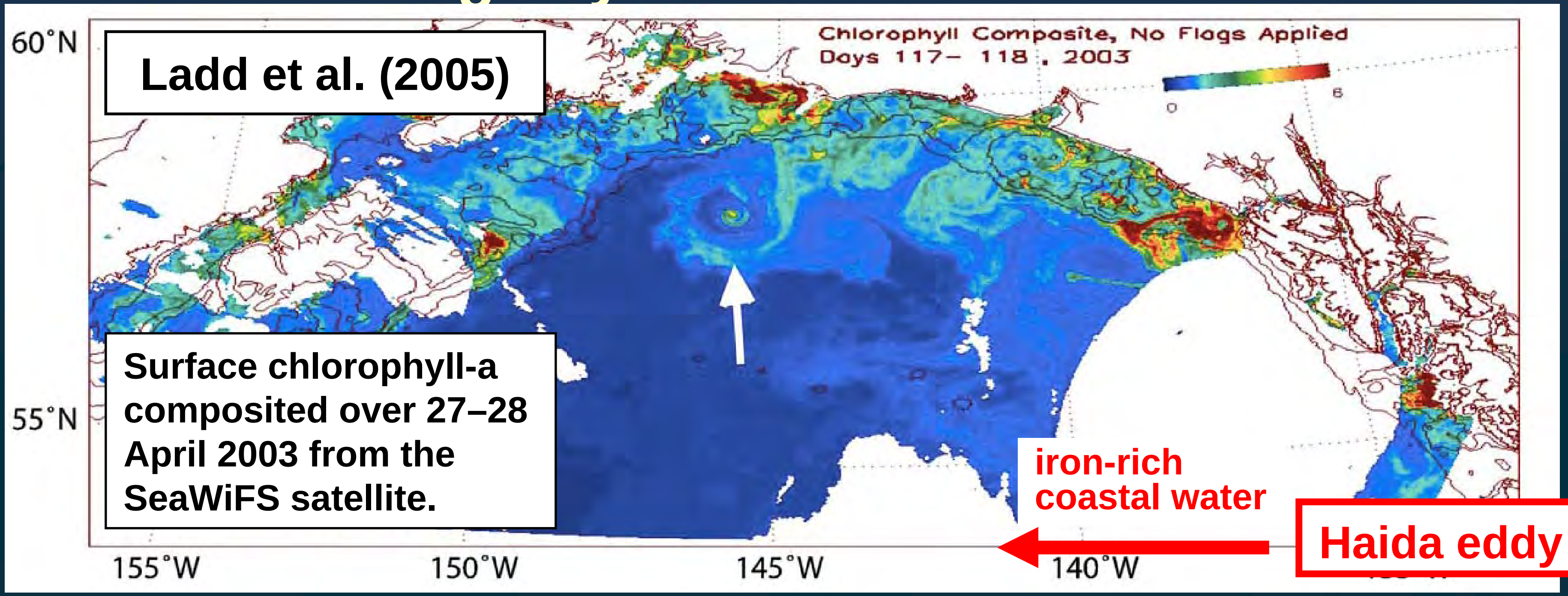
Alaskan Stream (AS)

- a connection btwn AG, WSAG & BSG
- volume, heat & freshwater transports (Onishi & Ohtani 1999)
- Anticyclonic eddies



Tracks of anticyclonic eddies (Crawford, 2002)

Water exchange by eddies in the GoA



Eddies in GoA: **heat, freshwater, nutrient & biota exchange** between shelf & off-shore regions by

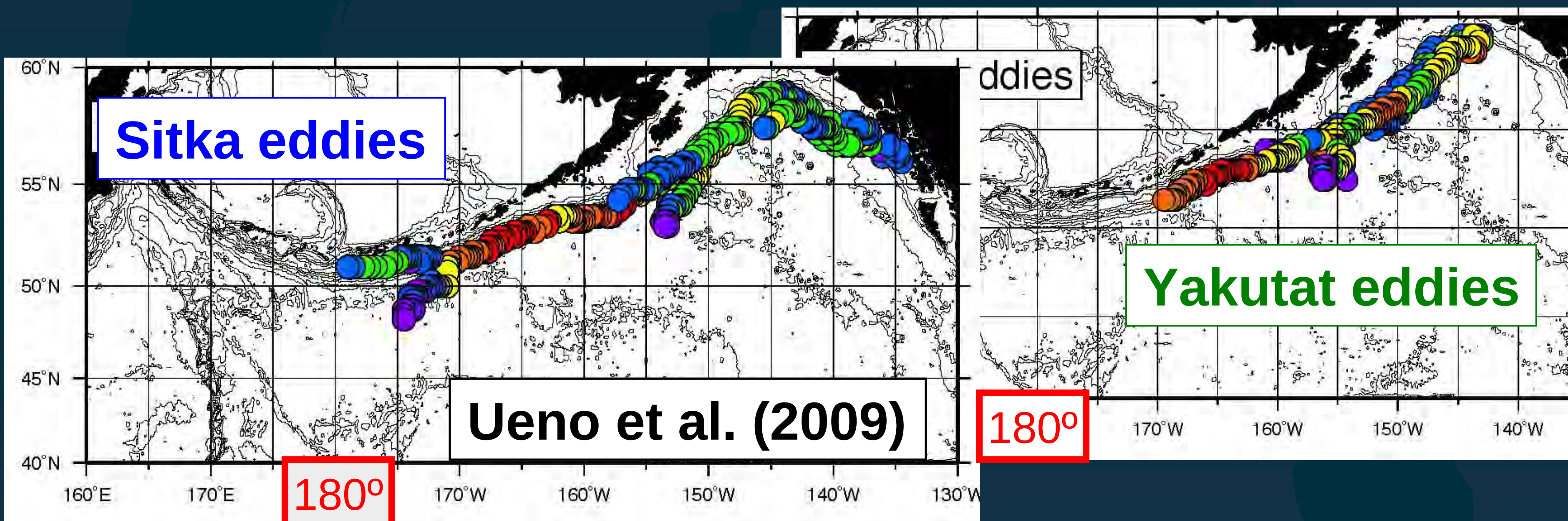
- Containing shelf water at the eddy center & propargating offshore
- Advection in the outer ring of the eddy.

(Crawford et al., 2005; Okkonen et al., 2003, Ladd et al., 2005; …)

Johnson et al. (2005): Haida eddies supply the central GoA (HNLC area) with **iron-rich** coastal water.

Some eddies in GoA went out of GoA. (e.g. crawford et al.,2000; Ladd et al., 2007)

Ueno et al. (2009) studied anticyclonic eddies propagating westward along the AS from GoA.
=> 12 long-lived eddies were observed from their formation.

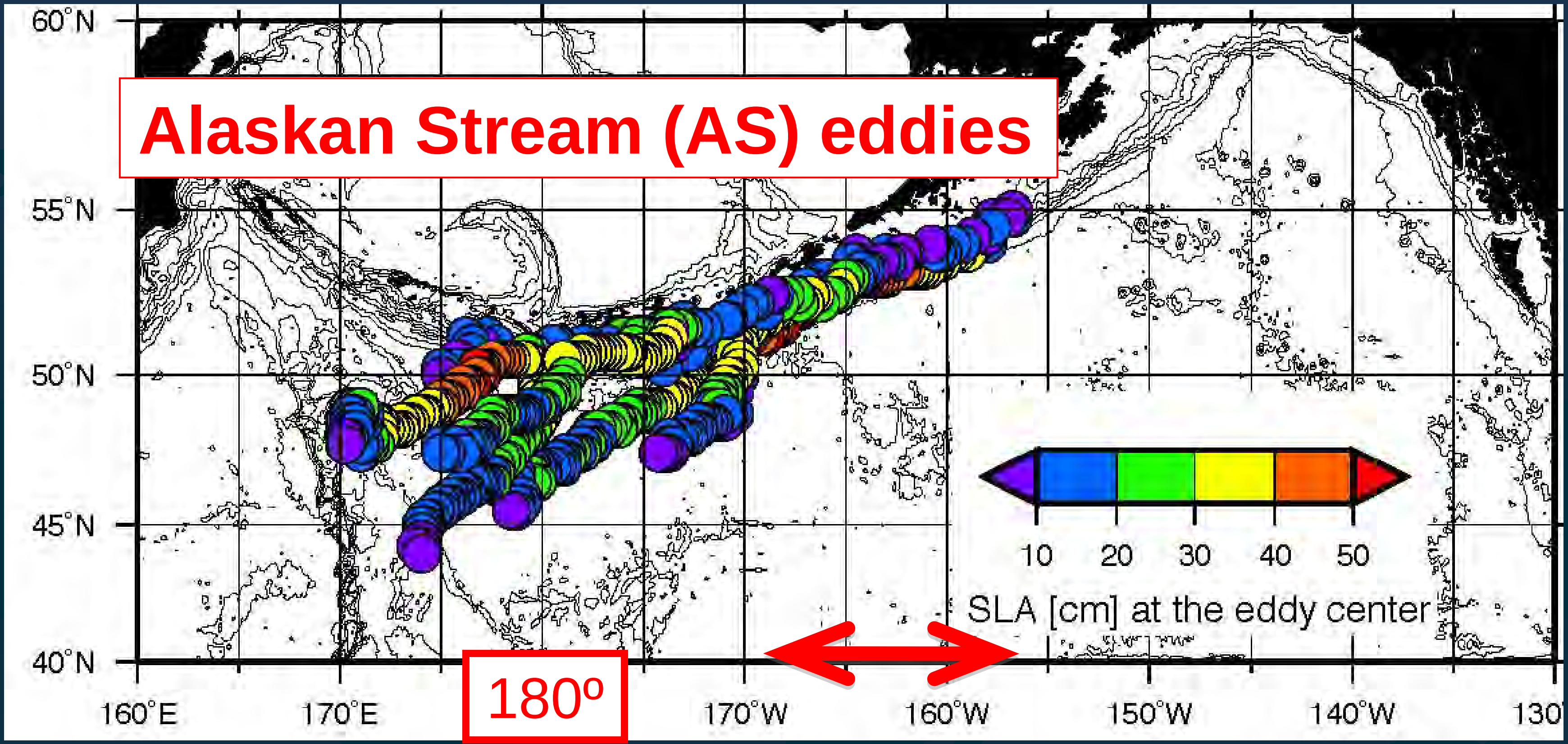


3 eddies: formed off Sitka (Sitka eddies)

4 eddies: formed around Yakutat (Yakutat eddies)

=> did not propagate west of 180º.

Ueno et al. (2009)



5 eddies: formed in the AS south of AP/AI. btwn 157º & 169ºW
=> AS eddies
AS eddies crossed 180º, providing central SNP with heat & freshwater comparable to surface fluxes.
=> affecting T/S and circulation in the central SNP

Formation of AS eddies (Ueno et al., 2009)

Thomson (1972) investigated the AS via **Steady, barotropic frictional BL theory.**

AS: ~zonal, west of 160W:

=> weak meridional flow

=> low planetary vorticity supply

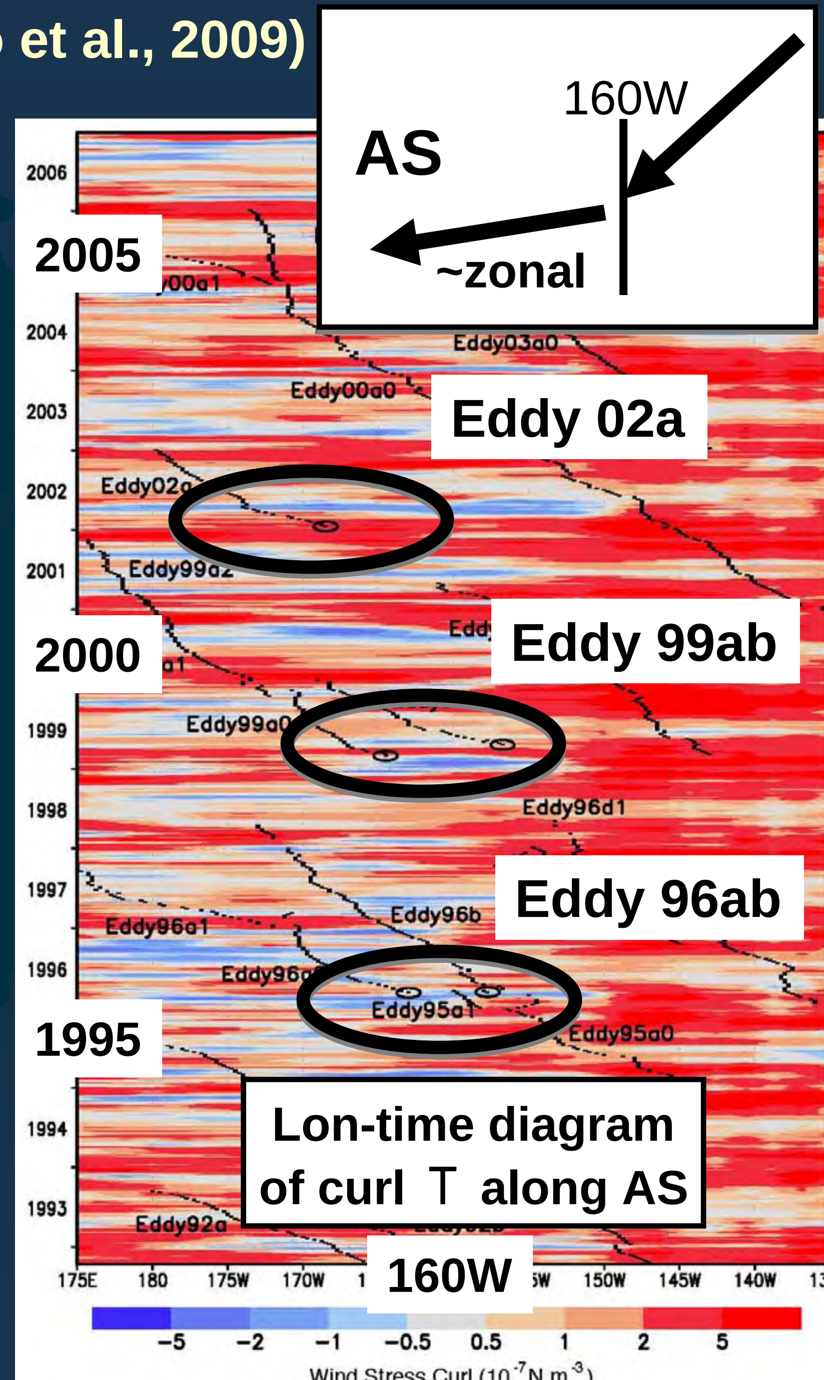
=> WBC Vorticity balance breaks

=> AS separation (anticyclonic eddy formation) … more likely occurs when curl τ negative.

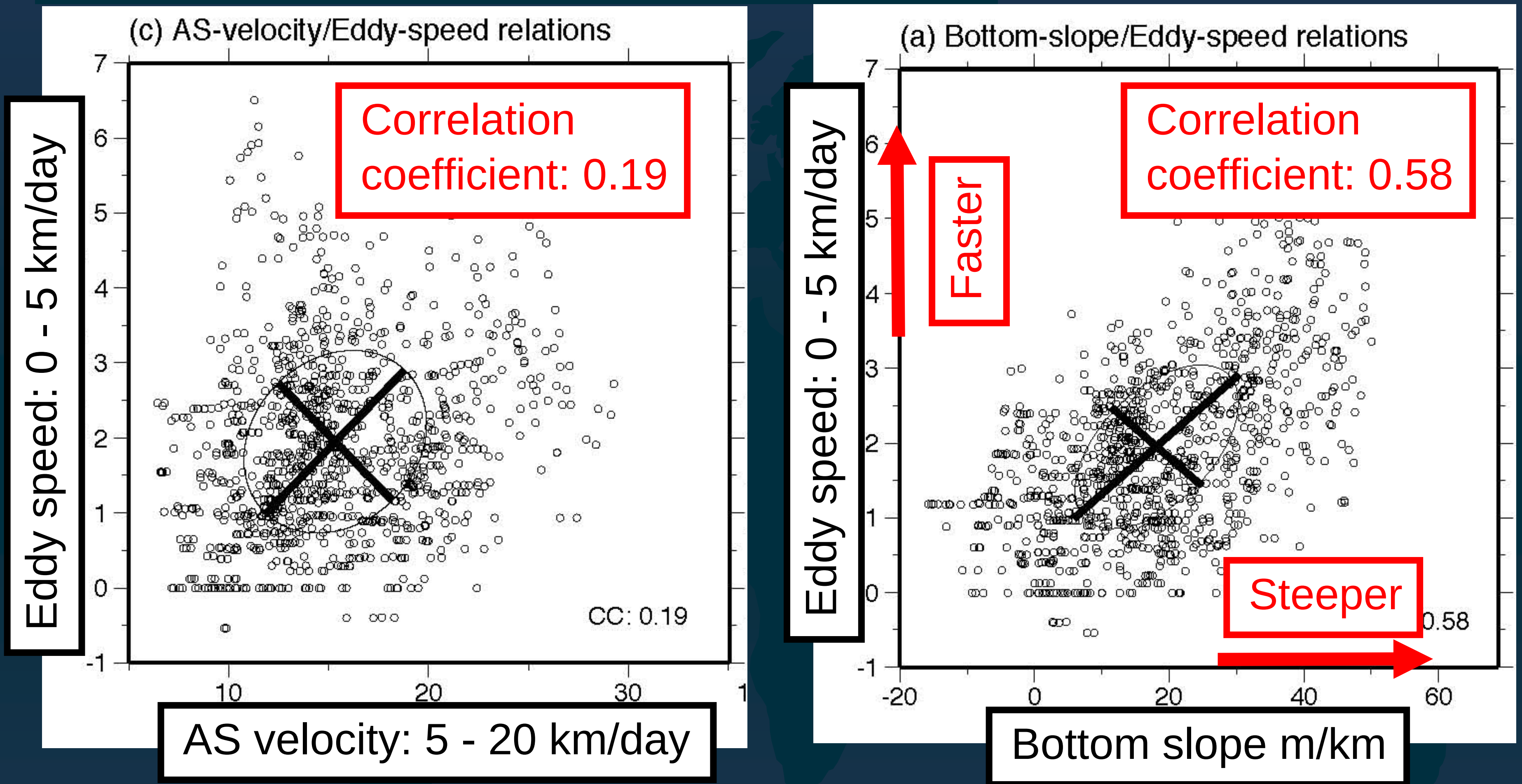
Eddy 96ab,99ab formed during or just after negative or weakly + curl τ

=> curl τ contributed to the formation of these eddies.

Eddy 02a: strong positive curl τ, which likely stabilized AS =>other formation mechanisms



Eddy speed (Ueno et al., 2009)



Comparison of eddy speed with AS velocity, bottom slope and SLA showed bottom slope effects to dominate, with faster propagation over steeper slopes.

Purpose of this study

Although previous studies investigated **formation and propagation** of AS eddies and their impact on T/S fields in the central SNP, the impact of AS eddies on the **biological production** has not been studied.

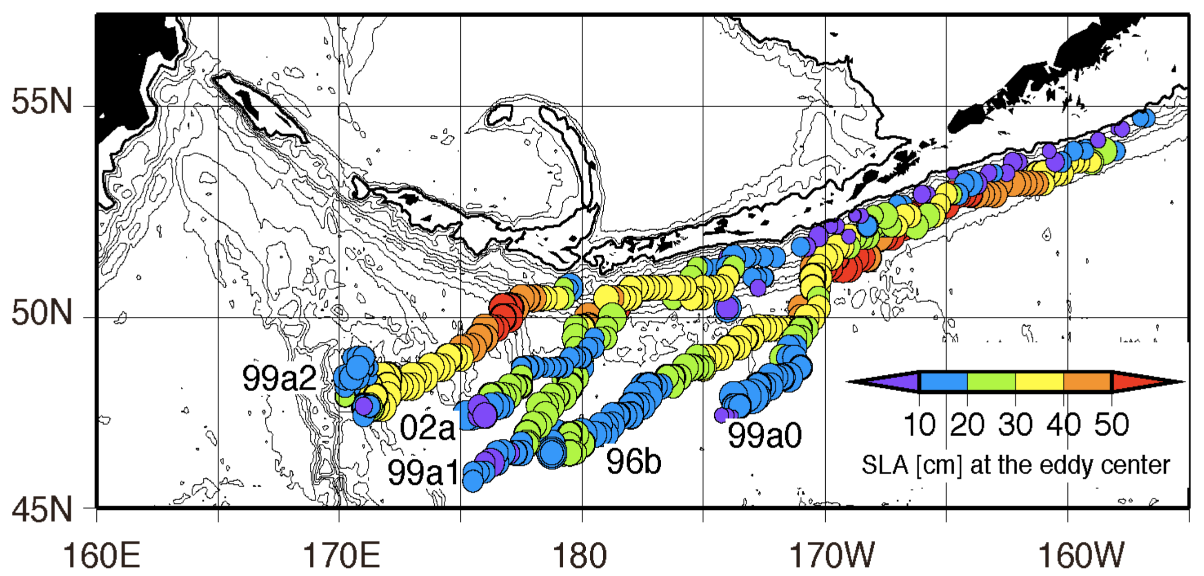
Therefore, we investigate the **chl-a** combined with sea level anomaly distribution to understand the **relation between AS eddies and the biological production** in the central SNP.

Data

- **SeaWiFS** Level 3 monthly composite chl-a concentration data
- **AVISO** Sea Level Anomaly (SLA) & absolute dynamic topography (ADT) data
- **Net primary production** (NPP) data (**OSU**, Behrenfeld & Falkowski, 1997)

Method

- We concentrated on the AS eddies that formed south of AP/AL
  => **5 AS eddies were found** (same as Ueno et al., 2009)



Eddy radius (R_{eddy}): estimated using Okubo-Weiss parameter W
(Okubo, 1970; Weiss, 1991, Isern-Fontanet et al., 2003,4,6; Chelton et al., 2007; Henson and Thomas, 2008).

Okubo-Weiss param. W

$$W = s_n^2 + s_s^2 - \omega^2,$$

$$\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad s_n = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}, \quad s_s = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}.$$

Vorticity, Strain (normal, shear)

Eddy core: area of W < -0.2 σ_w

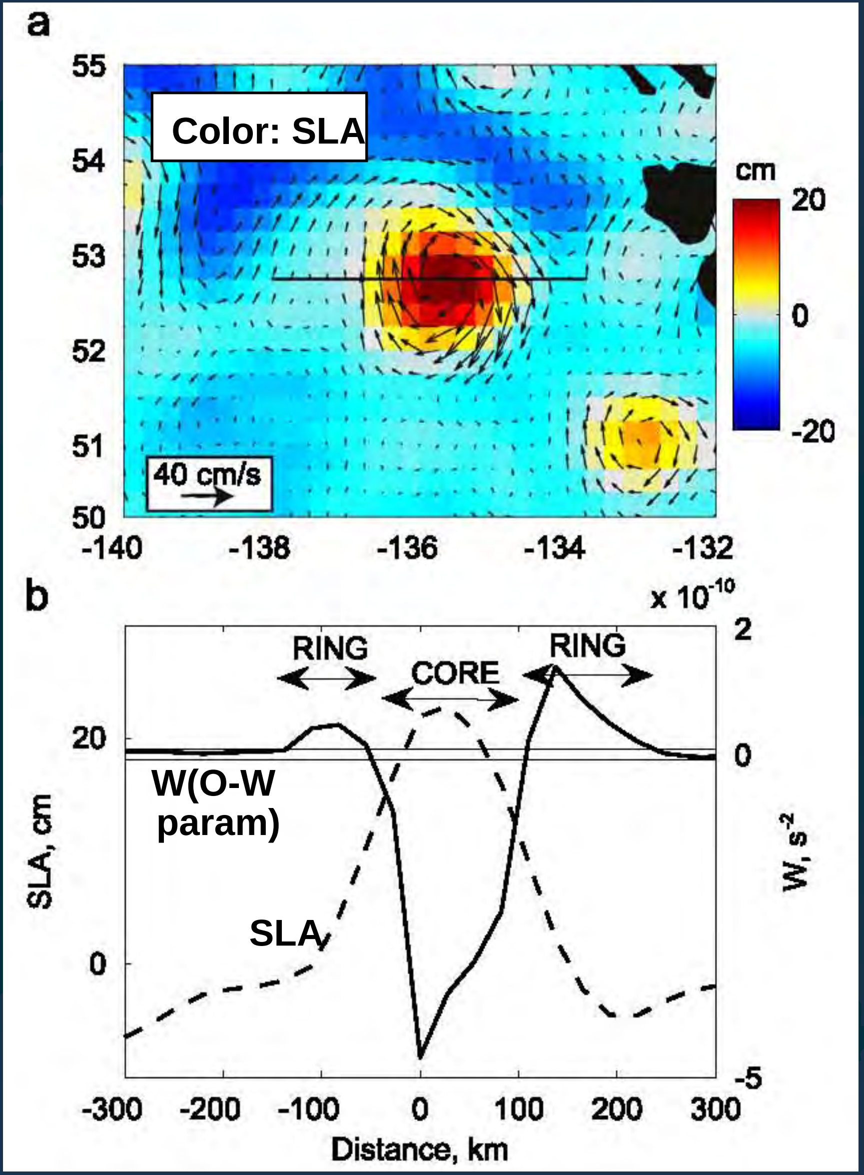
σ_w=SD of W over the region

$2\pi R_{eddy}^2$ = (area of W < -0.2 σ_w).

=> R_{eddy}: 34 - 95 km,

69 km on an average,.

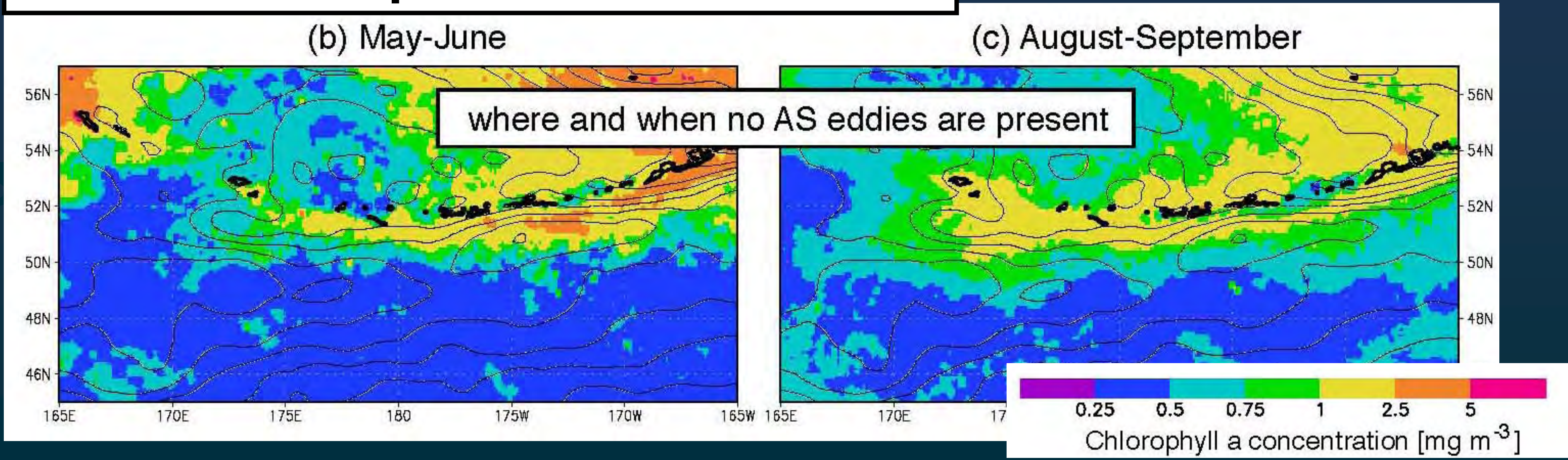
Trajectories and sizes of AS eddies => **monthly clim. chl-a maps with** (< $3R_{eddy}$) & **without** (> $3R_{eddy}$) **AS eddies**.



Henson & Thomas (2008)

Results

Clim. chl-a maps **without** AS eddies

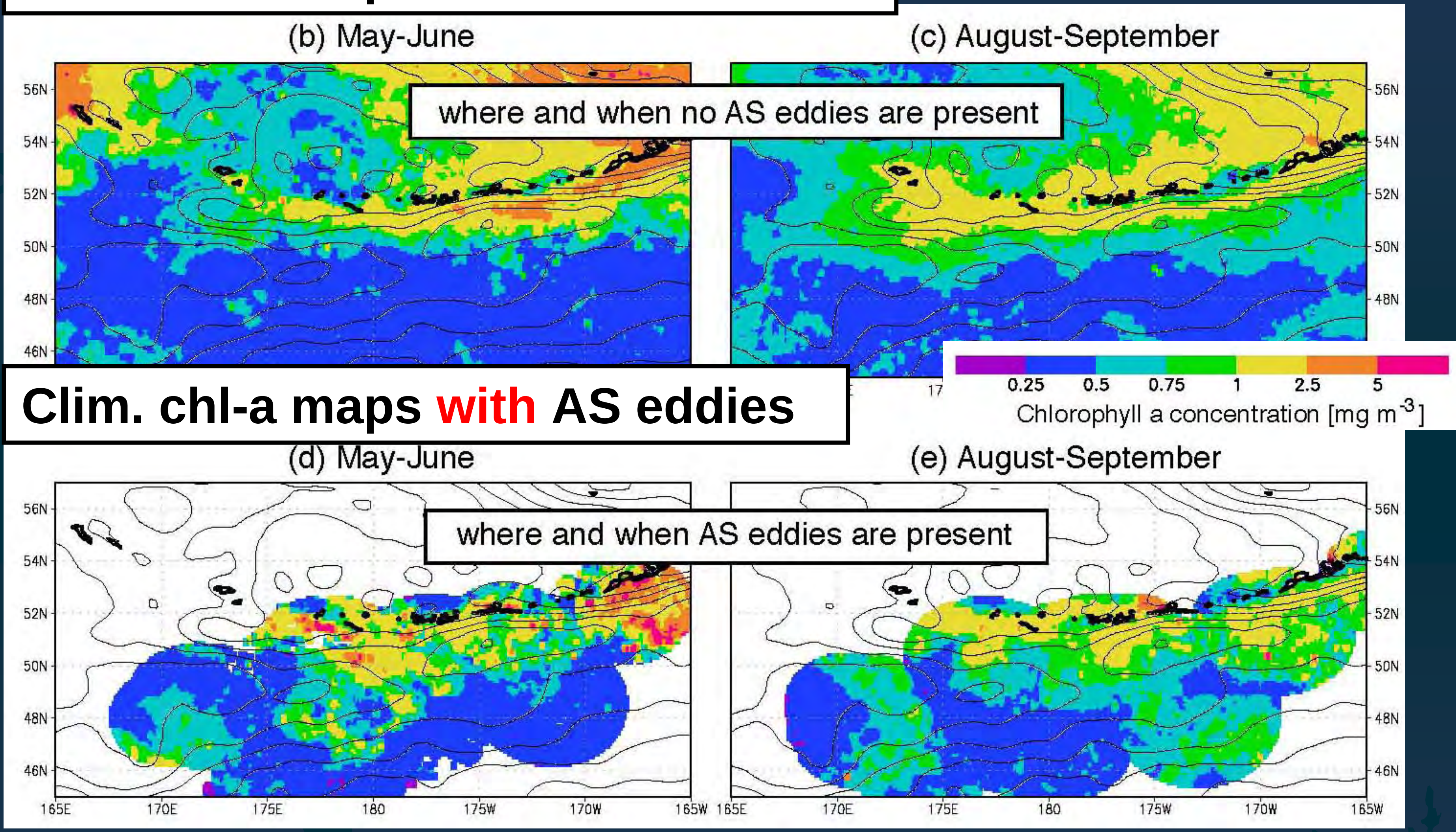


High chl-a: observed in the area **just south of the AI**
<= AS transported nutrient-rich water (Ladd et al., 2005a; Mordy et al., 2005).

Low chl-a: observed **in the deep-sea region** of the central SNP
=> **low productivity in the area**

Clim. chl-a maps without AS eddies

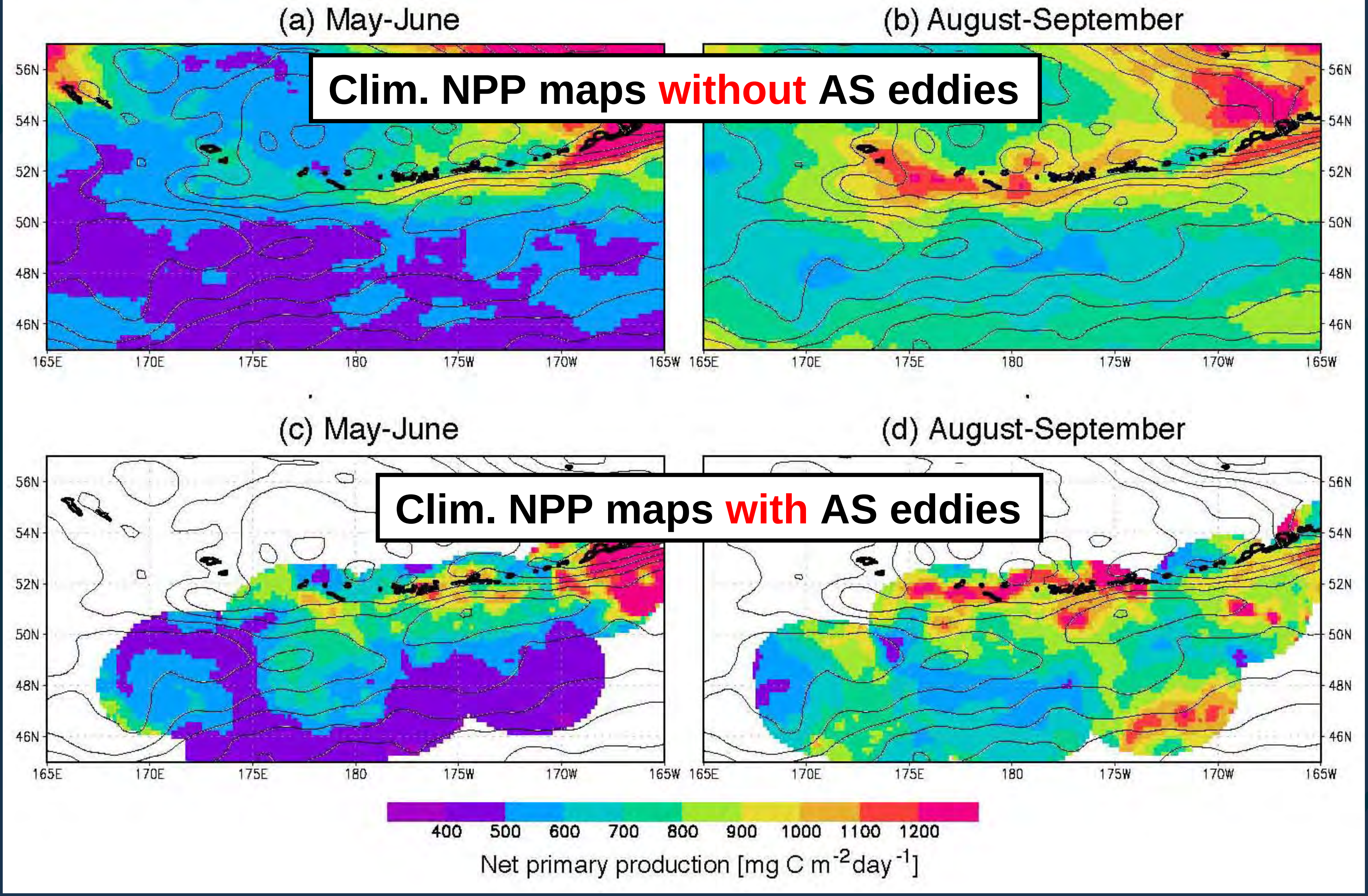
Clim. chl-a maps with AS eddies



High chl-a: observed even in the deep-sea region of the central SNP

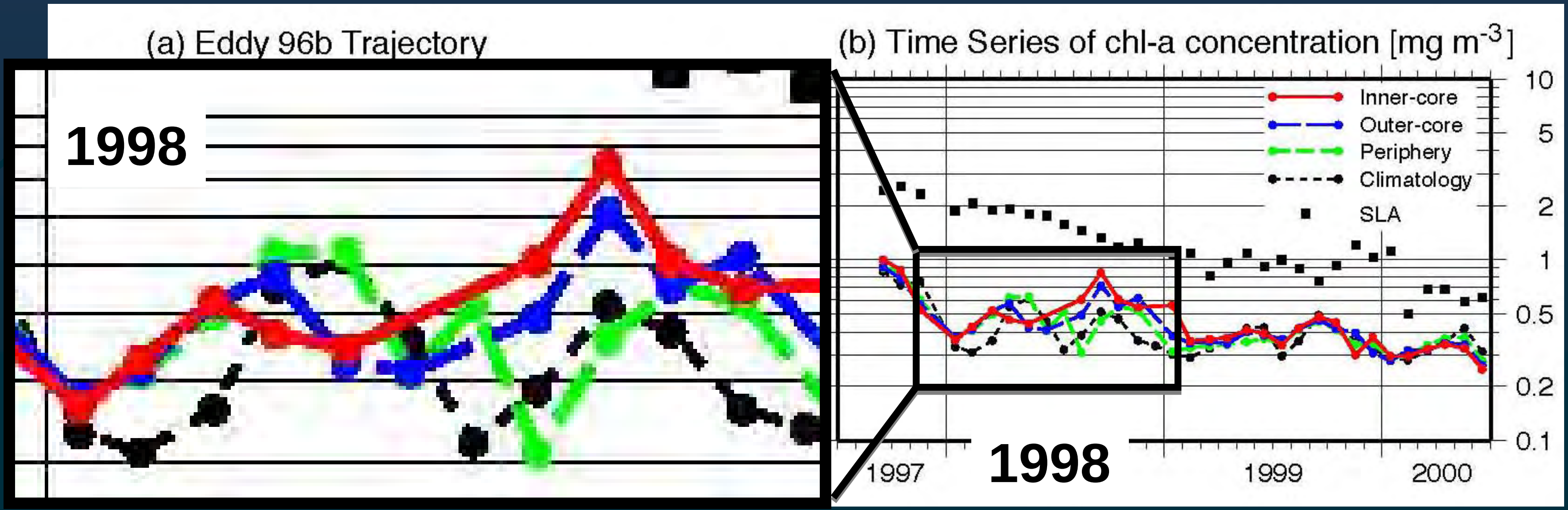
=> AS eddies contributed to the productivity in the deep-sea region of the central SNP.

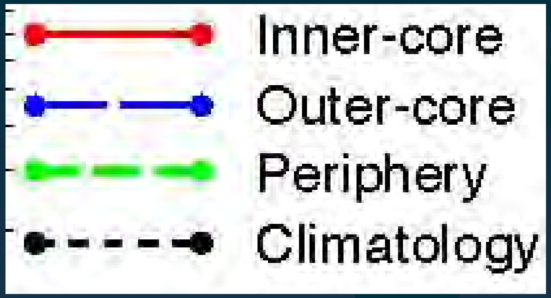
Clim. Net primary production (OSU)



AS eddies enhance NPP in the deep-sea region of the central SNP

Distribution of chl-a in & around each AS eddy





$D < 0.5R_{eddy}$

$0.5R_{eddy} < D < R_{eddy}$

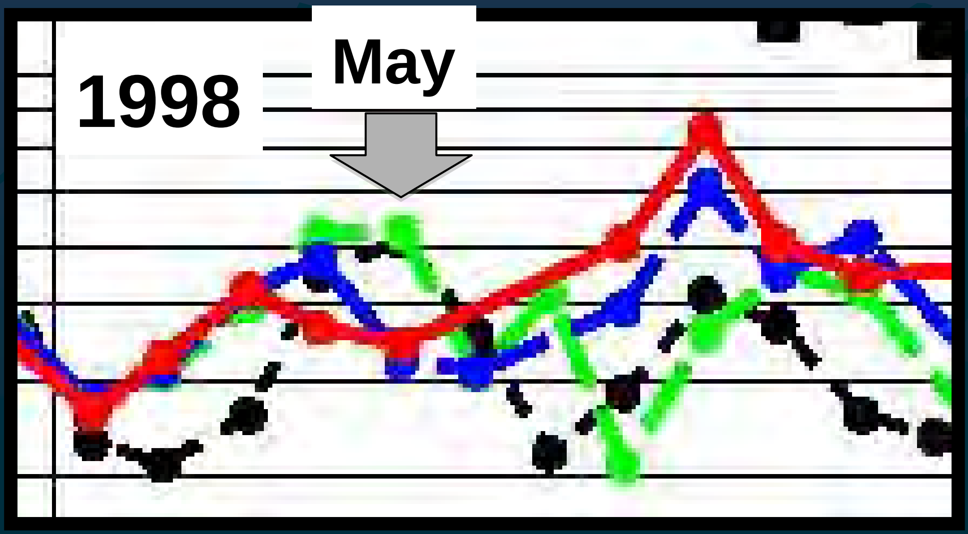
$R_{eddy} < D < 2R_{eddy}$

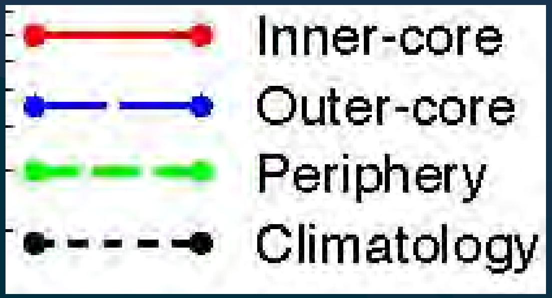
$D < 2R_{eddy}$

Spring & fall: chl-a relatively high

=> Corresponds to spring & fall blooms

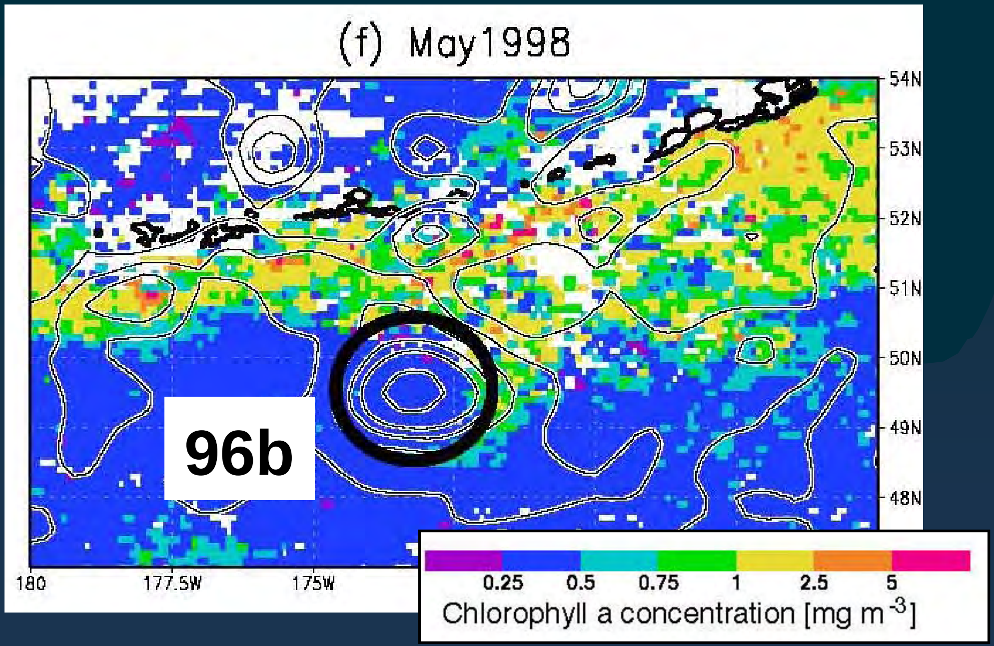
Example: Eddy 96b



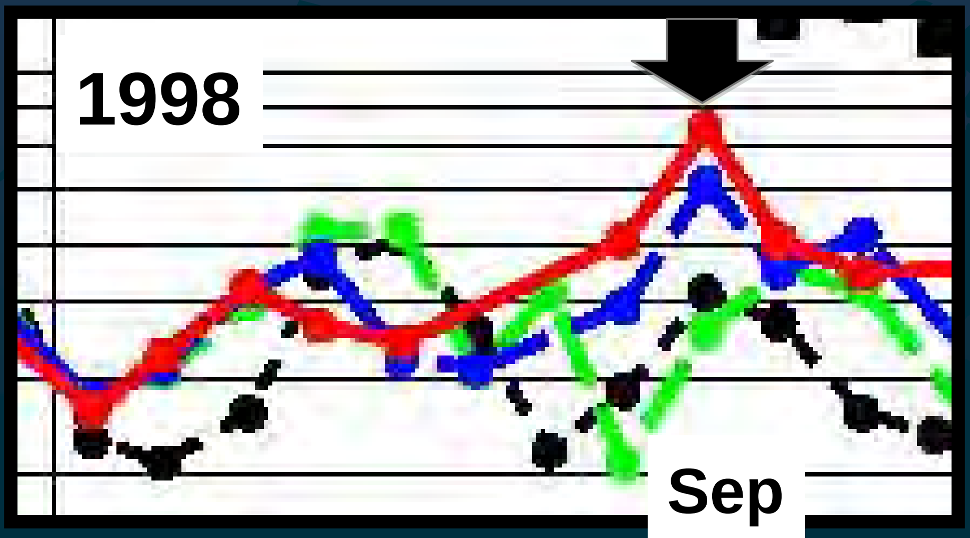


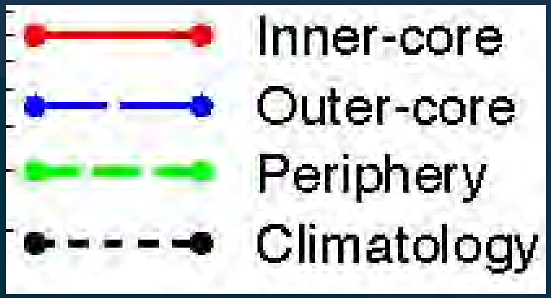
May 1998 (just after 96b detached from AS):
Chl-a: high in periphery

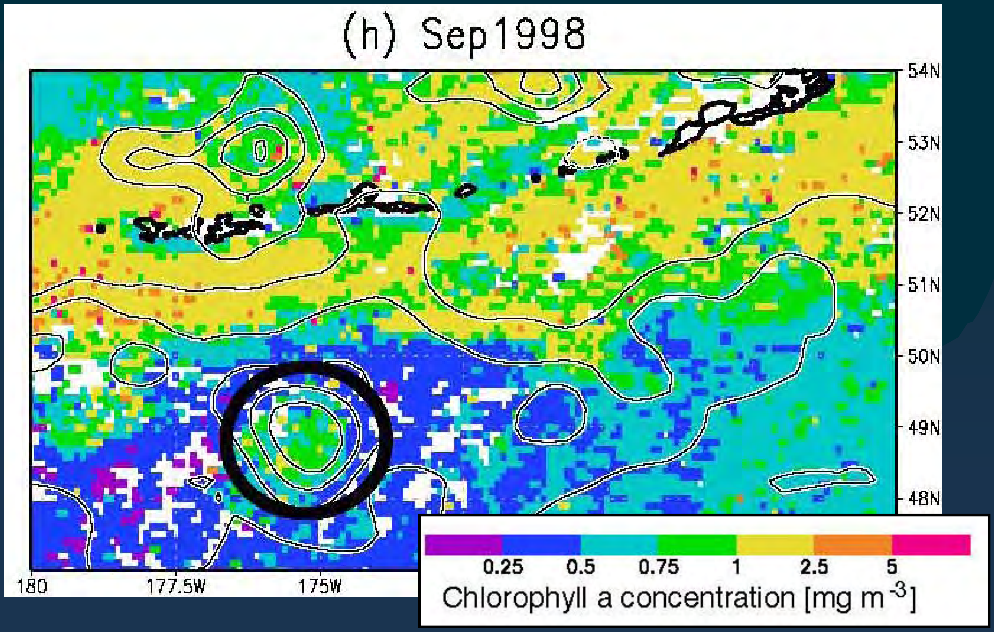
=> Tongue-shaped high chl-a area in the eastern side
=> Southward adv of chl-a-rich water from area just south of AI



Example: Eddy 96b







Sep 1998 :

Chl-a: high only in the core & low outside of the core

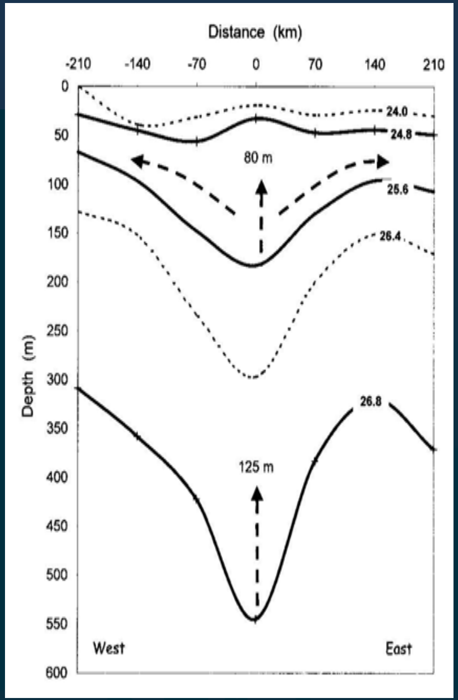
=> Horizontal adv is unlikely to cause the high chl-a

=> Possibility of upwelling

Possible mechanisms

Isopycnal rebound due to eddy decay
(Whitney and Robert, 2002)

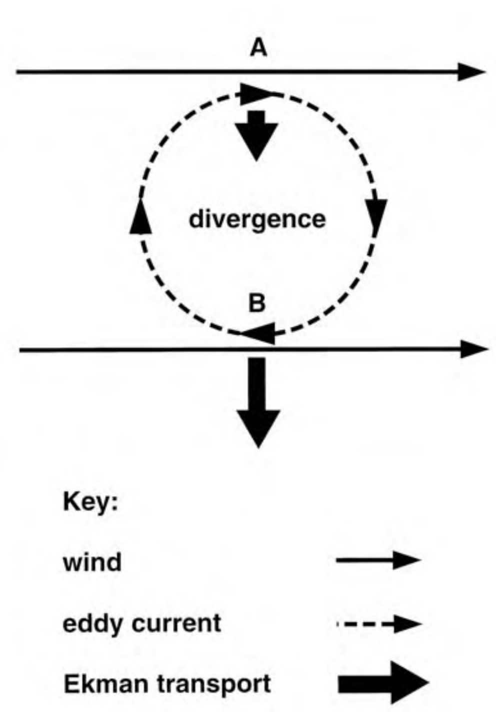
=> supplying euphotic zone with micro-nutrient



Whitney and Robert (2002)

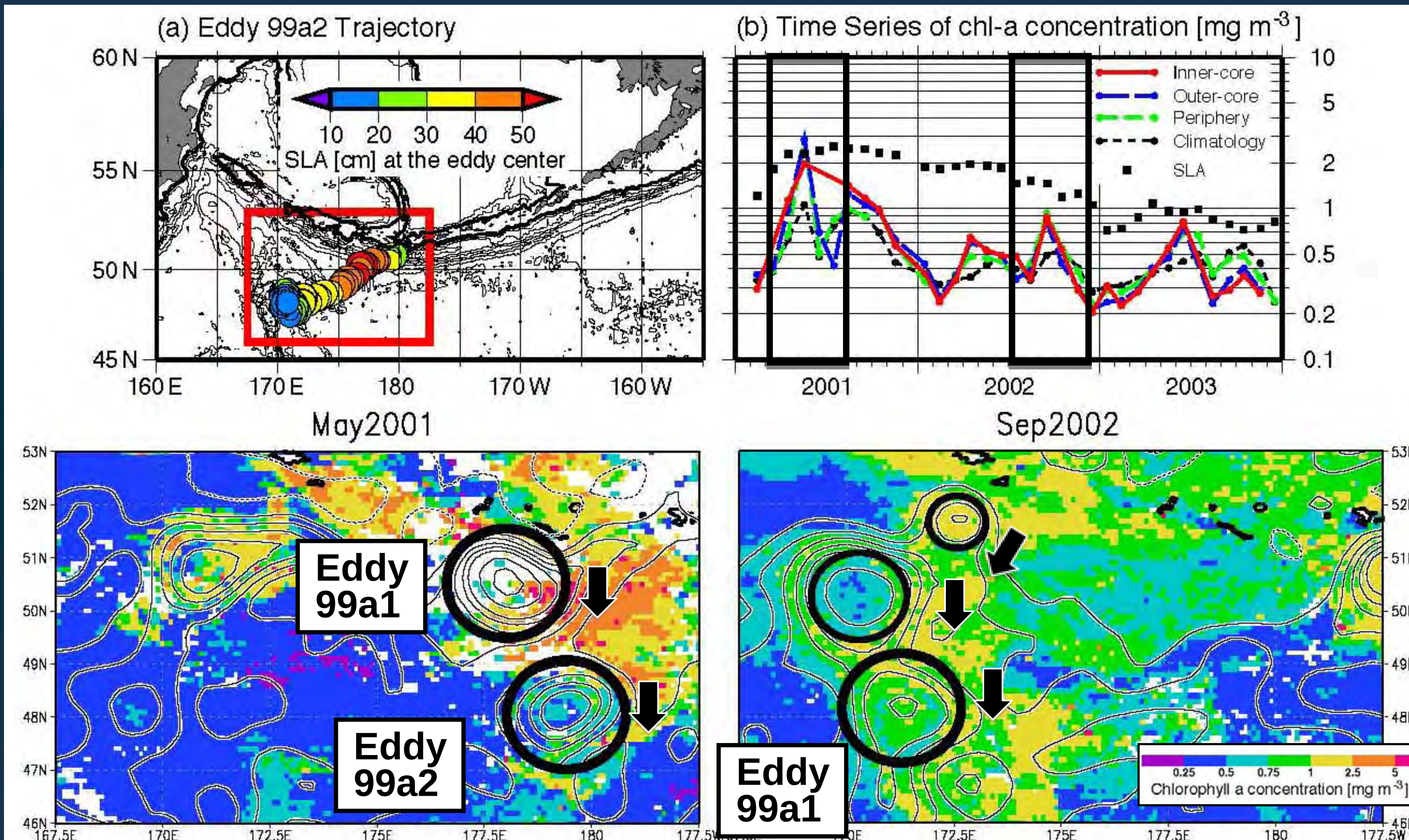
Upwelling due to eddy-wind interaction
(Martin and Richards, 2001; McGillicuddy et al., 2007)

=> Anticyclonic surface water current induces divergence of Ekman transport at the eddy center, resulting in upwelling at the eddy center.



Martin and Richards (2001)

Example: Eddy 99a1,99a2

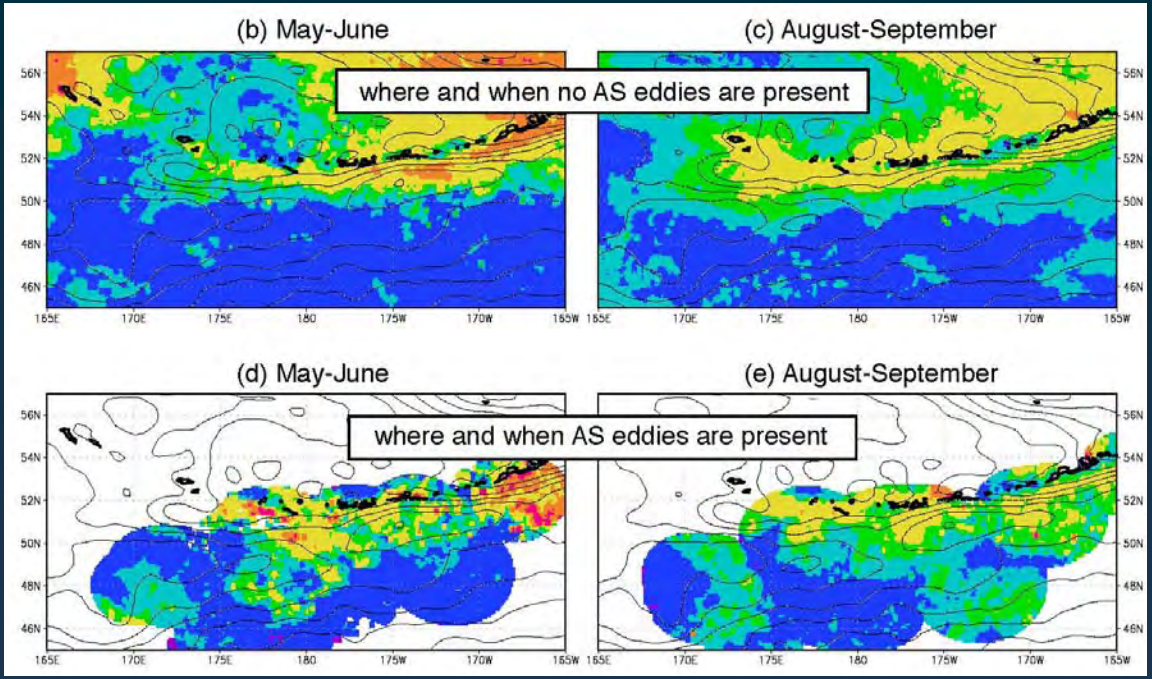


High chl-a was observed in the area east of a combination of two or three eddies. This might be caused by macro- and micro- nutrients & biota transports from the AI through southward advection.

Summary 1/2

The impact of the AS eddies on the chl-a distribution in the central SNP was investigated through analysis of chl-a and altimetry data from satellite observations.

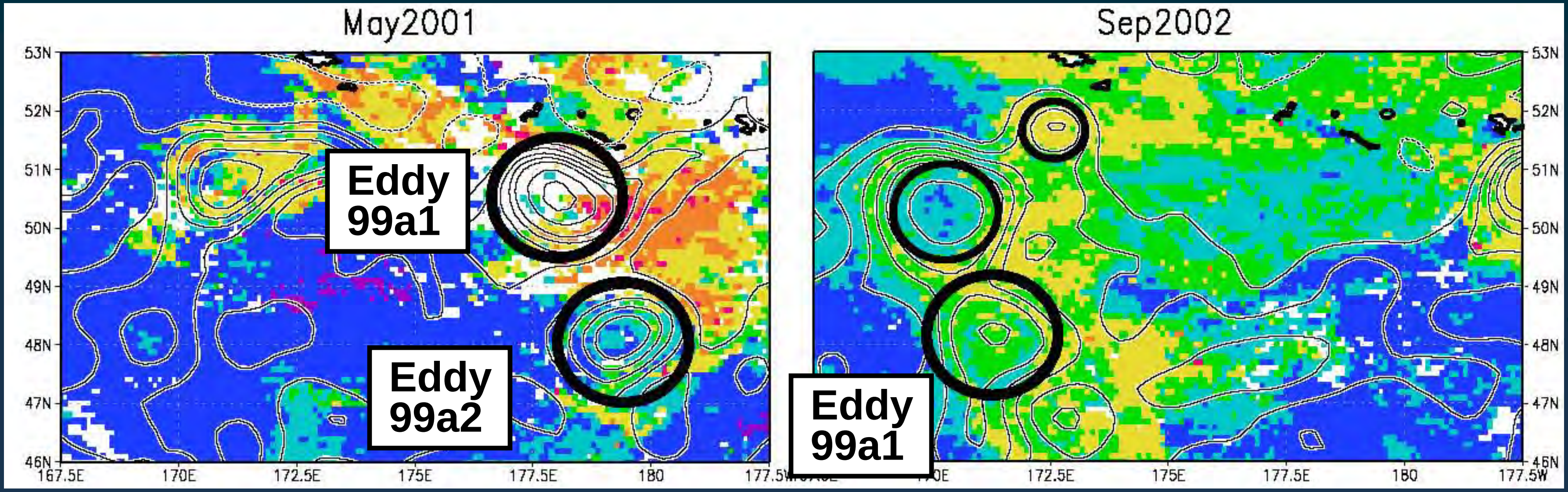
1. **The climatological chl-a distributions averaged in the areas with and without AS eddies suggested that AS eddies contributed significantly to the chl-a distribution in the deep-sea region of the SNP.**



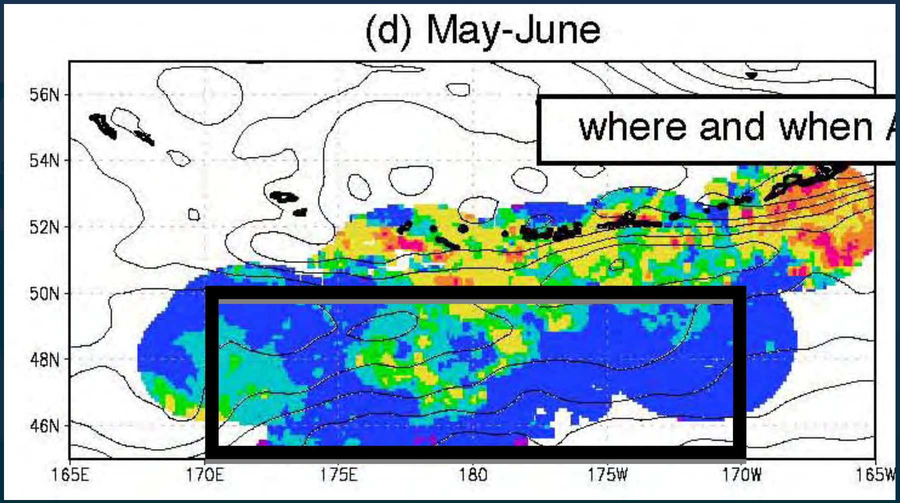
Summary

2. The chl-a distribution was closely related to the AS eddies regardless of whether the eddy was located in or detached from the AS.

3. A combination of two or three AS eddies sometimes formed high chl-a concentration belts that injected chlorophyll and nutrient-rich waters southward from the AI far into the deep-sea region of the SNP.



Impact of AS eddies



The percentage of chl-a due to AS eddies in the the area of 170ºE–170ºW & 45º–50ºN : 18.4%

=> significantly higher than the percentage of the area of AS eddies of 14.5%

=> Chl-a distribution in the deep-sea region of the central SNP is significantly affected by the AS eddies.